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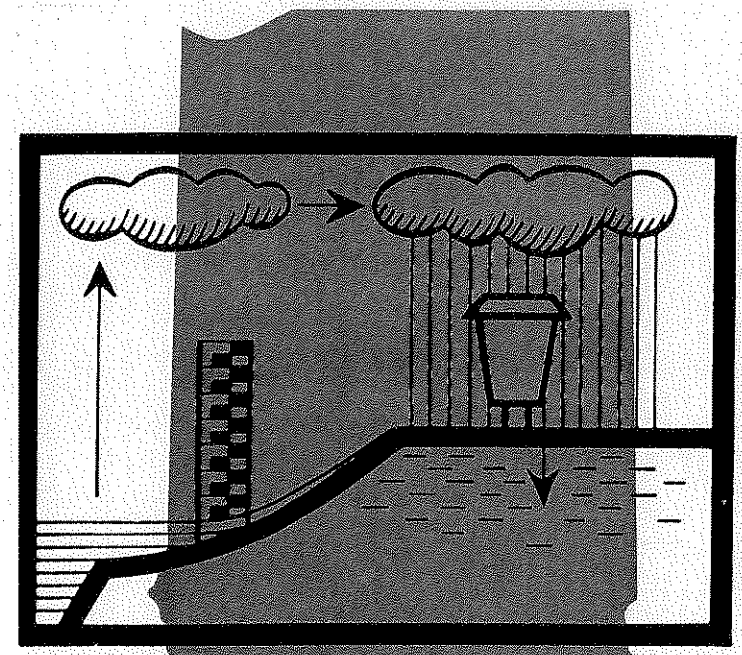
CHEMICAL SPECIATION OF LEACHATES FROM WASTE DISPOSAL SITES



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Chemical Speciation of Leachates from Waste Disposal Sites

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SUMMARY

Data were obtained from the literature on the chemical composition of wastewater applied to soils and the concentrations of constituents in soil leachates and groundwaters beneath sites irrigated with wastewater. Total analytical data for metals and ligands were used as input for an equilibrium chemical model (GEOCHEM) to evaluate metal-ligand species present. The results indicate that wastewaters and soil solutions contain sodium and potassium as the free metal ion while inorganic complexes of calcium and magnesium are present in many natural systems and wastewaters. The speciation of trace metals was very dependent on the concentration of organic carbon in the solution along with the amounts of inorganic ligands such as borate and phosphate. Borate complexes of trace metals (nickel, cadmium, lead, zinc) could be an important species in many calcareous soils and groundwaters.

INTRODUCTION

Application of municipal wastewater on land includes slow rate, rapid infiltration or overland flow systems. The primary objectives of land application include plant uptake of wastewater-borne nutrients, adsorption of trace metals and organic chemicals and removal of pathogens by filtration and die-off. If wastewater constituents are not retained by the soil, continued percolation can result in contamination of groundwater. Other concerns related to waste application to soils include increases in soil salinity and associated adverse effects on soil physical properties and plant growth and toxicities of heavy metals to plants resulting in decreased crop yields.

Recently there has been an increase in available data on the changes in groundwater composition after long term applications of wastewater (1,2,3,4,5,6). The information available lists the total concentrations of metals and ligands in wastewater and groundwater, which is readily amenable to calculations yielding the species of metals and ligands. Such an evaluation of the data would be very useful since the form of a metal or ligand in a wastewater or soil solution may determine its behavior and fate in soil. For example, metal uptake by plants is related to metal activity rather than total concentration. The speciation of groundwater constituents can be examined to understand the form of a metal leaching into groundwater.

The computer program GEOCHEM (7) calculates the metal and ligand species present in groundwater, soil solution or wastewater samples, if a complete chemical analysis of the sample is available. GEOCHEM is an iterative program and is an expanded version of the computer program REDEQL2 (7,8). The program uses thermodynamic formation constants corrected for ionic strength to calculate the concentration of metal-ligand complexes in a solution.

The purpose of this study was to determine the speciation of metals and ligands in effluent and groundwater for sites treated with wastewater. Results from studies involving long-term wastewater treatment sites were the sources of input data for the computer program GEOCHEM.

MATERIALS AND METHODS

Data for wastewater and groundwater were taken from U.S. EPA publications summarizing the environmental effects of the land application of wastewater. Selection of data sets was based on the availability of complete chemical analysis data for water samples. Complete analysis data is essential to compare speciation calculations for wastewater and groundwater samples.

Studies conducted at six sites were selected as data sources (1-6). A short description of each site is shown in Table 1. The reader is referred to the original publications for a more thorough site description.

Hollister, California

The study area was a rapid infiltration system that had been operating for more than 30 years (1). Industrial wastes from a slaughter house and a paper recycler along with domestic sewage from the city of Hollister were the major inputs into the municipal system consisting of primary treatment. Average values for the effluent, and monitoring wells beneath the rapid infiltration system and an adjacent nonirrigated site were used as input data (Table 2). The wells under the treated site were designated as either shallow (well 3A), intermediate (well 3B), or deep (well 2C) and were 7.6, 21, and 48 m deep, respectively.

Milton, Wisconsin

This site was a rapid infiltration system that had been operating for more than 20 years. Treated wastewater from the town of Milton is applied to the site at an estimated rate of 244 M per year. Initially the treated effluent is pumped into an infiltration lagoon before being applied to the site. Mean values for the treatment plant effluent, storage lagoon effluent, and monitoring wells for a nonirrigated site (control well; > 22 m deep) and for the irrigated site (shallow, < 16.8 m deep; deep, > 22 m deep) served as input data (Table 3).

Dickinson, North Dakota

The site was a slow rate irrigation system that had been operating since 1959. Wastewater from the city of Dickinson was applied to a 5.7 ha irrigation site. Average values for the effluent applied and groundwater samples taken from monitoring wells situated in either the sentinel butte or alluvium aquifers. Monitoring wells were located in the alluvium and sentinel butte aquifers beneath the irrigated area while only the sentinel butte aquifer was sampled in an adjacent control area (Table 4).

Tooele, Utah

This site was a slow rate irrigation system that had received secondary treated municipal effluent for 20 years. The nonindustrial community of Tooele was the effluent source. A mixture of pasture grass and alfalfa was grown on the irrigated area and was harvested during the summer months. Mean values for the wastewater, effluent from a holding lagoon prior to irrigation and conventional irrigation water served as input data (Table 5). Complete groundwater analysis data was not collected at this site.

Cape Cod, Massachussetts

This site was on the Otis Air Force Base and involved slow rate irrigation of mixed grasses. Secondary treated wastewater from the Otis Air Force Base sewage treatment plant was applied to the area through a

spray irrigation system. Mean values were taken for the effluent, a monitoring well for a nonirrigated control area, and lysimeter samples from the treated area (Table 6). The control well was 7.6 m deep and the lysimeters were placed at 15 cm and 60 cm below the soil surface.

Boone County, Kentucky

This site consisted of four sanitary landfill test cells that were filled with municipal solid waste. The cells were constructed to test the feasibility of comparing a small-scale system with a large-scale sanitary landfill. Analysis data for leachate samples from cells 2A, 2B, and 2D served as input data (Table 7). Samples that were taken quarterly during the 4 years of sampling were run through GEOCHEM. Test cells 2A and 2B were constructed in steel pipes that were 1.83 m in diam. and 3.66 m long. Test cell 2D was a 8.53 m^2 and was constructed in a similar manner to a normal sanitary landfill cell. Since cell 2D approximates a typical sanitary landfill, three years of leachate data were analyzed.

Data Analysis

Total concentration values for the inorganic ions and organic C in the water samples were converted to -log [M] and input into the computer program GEOCHEM (7,9) at the reported pH. The complexation of each metal with inorganic and organic ligands in each water sample was calculated directly by the program.

A significant portion of metals can be complexed by soluble organic ligands. Since the water samples were not analyzed for specific organic ligands, it was not possible to calculate directly the complexation of metals by soluble organics. The complexation of metals by organics was calculated by using a model for soluble organic C in water samples. Mattigod and Sposito (1979) selected a group of organic acids at specified concentrations to match the acidic functional group classes in sludge-derived fulvic acid (FA). Nine organic acids were combined at concentrations to give a pH titration curve that closely resembled the titration curve for the sludge FA. The concentration of organic acids in the model was 10^{-3} M which is equivalent to 226 mg organic C/ℓ. The measured soluble organic C value in mg C/ℓ was converted to a molar concentration of each organic acid used in the model to evaluate the complexation of metals by organics in each water sample. The number of complexes present depended on the number and concentration of sample constituents analyzed.

RESULTS

With the exception of the Boone County, Kentucky site, all of the data evaluated in this project involved the long-term application of wastewater to soils. One objective of the U.S.EPA supported studies was to see how the chemical composition of groundwater changed as a result of the land application of wastewater. The current project was

undertaken to expand the interpretation of data obtained in these studies. We took representative data from each study and calculated the species of metals and ligands in the wastewaters and in groundwater from the treatment areas.

Hollister, California site (1)

The Hollister rapid infiltration system received an average of 64.6 m of wastewater per year (Table 1). In general, the concentration of metals in groundwater from the test area wells were either higher than or similar to the effluent and control well (Table 2). Manganese in the shallow test well was much higher than in the effluent applied, suggesting that anaerobic conditions induced by irrigation resulted in reduction of soil-borne Mn oxides. The concentrations of anions followed a pattern similar to the metals. Phosphate was an exception in that it was essentially removed from solution at a depth of 21 m (intermediate test well; Table 2). The concentrations of all elements in both the wastewater and groundwater were below EPA drinking water standards (1). The water samples were alkaline ranging in pH from 7.3 for the effluent to 7.9 for the deep test well.

When data from the Hollister site (Table 2) were evaluated by GEOCHEM, the 11 metals and 18 ligands could have combined to form 406 possible complexes and 57 possible solids. Those species that totaled more than 0.1% of the total metal are listed in Table 8, except for phosphate complexes. Phosphate complexes accounted for 1.3% of Pb and

1.1% of Zn in the effluent and 1.3% of Ni, 1.1% of Pb, and 1.6% of Zn in the shallow well.

In general, Ni, Ca, Mg, and K were present essentially as free hydrated ions in solution (Table 8). The only exception was the effluent in which 29.3% of the Ca was complexed with the model fulvate ligand. Copper, iron, and manganese existed as complexes rather than free ions in nearly all water samples.

The differences in speciation of trace metals for the samples can be directly related to the concentration of organic carbon (Table 2 and Table 8). This is especially evident if the distribution of Ca, Ni, Pb, and Zn in the effluent (Table 8) is compared to the distribution of these elements in the shallow and deep test wells. Complexation of the trace elements by soluble organics may explain why they were not removed from solution by the soil at the Hollister site.

When GEOCHEM was run to allow precipitates, the effluent and shallow well were oversaturated with respect to solid calcium phosphate. The intermediate test well was oversaturated with respect to ferric hydroxide. The lack of trace metal precipitates indicates that the water percolating through the soil may in fact dissolve soil-borne metals resulting in movement of soil- rather than effluent-derived metals.

Milton, Wisconsin site (2)

Approximately 244 m of wastewater was applied annually to the Milton, Wisconsin rapid infiltration site (Table 1). The concentrations of the components of the effluent and infiltration lagoon are very similar (Table 3),except for elevated concentrations of PO_4 and SeO_4 in the effluent. Concentrations of Cl, NH_3 and PO_4 in the control well were significantly lower than the test wells and infiltration lagoon, reflecting leaching of wastewater constituents into the ground water. Composition of water for the test wells was similar to the infiltration lagoon, indicating minimal removal of ions by the soil. As expected, organic C was similar for both deep control and test wells while the shallow test well was intermediate between the effluent and deep test wells. The pH of the samples differed by less than one unit, ranging from 7.5 to 8.1. According to the authors, NH_4-N was being placed in the groundwater at levels exceeding drinking water standards (2).

This set of input data had 8 metals and 19 ligands. When the species in these samples were calculated 260 possible complexes and 41 possible solids were considered. Table 9 lists all species that were present at concentrations contributing greater than 0.1% of the total metal. Data not included in the table included: 10.3% of Zn was complexed with $B(OH)_3$ in effluent; 7.1, 4.1, and 7.2% of Zn was associated with $B(OH)_3$ in control well, shallow test well and deep test well, respectively; 1.2, 2.1, and 1.6% of the Zn was complexed with OH in the control well, shallow test well and deep test well, respectively.

The predominant form of Ca, K, Mg, and Na was the free ionic species (Table 9), with minor amounts complexed by CO_3, SO_4, and Cl. In samples where Fe, Mn, and Zn analysis were complete, it can be seen that the fulvate ligand formed complexes with only Mn. The predominant form for both Zn and Fe was a CO_3 complex. There are no obvious differences in the speciation of the metals in the effluent and well samples, a reflection of the similarities in the composition of the samples.

All of the samples were oversaturated with respect to both solid calcium carbonate and calcium phosphate. In addition, the deep control well and deep test well were oversaturated with respect to solid zinc carbonate and the two test wells were oversaturated with respect to soild ferric hydroxide.

Dickinson, North Dakota site (3)

The Dickinson slow rate infiltration site received ≈ 1.4 m of wastewater per year (Table 1). Cadmium, Co, Hg, Ni, and Pb were essentially removed from solution by the soil (Table 4). The concentrations of Al, Fe, Mn, Na, Zn, and SO_4 were higher in the control wells than in the effluent. In contrast, PO_4 was 10^3 times greater in the effluent than in the control and test wells. Both organic C and pH were higher in the effluent than the monitoring wells and all solutions were alkaline with pH's of 7.2 to 8.7.

This data set had 16 metals and 19 ligands. There were 563 possible complexes and 96 possible solids considered in the calculation of the different species. Results from the computer output are summarized in Table 10. Data for the NH_3 complexes in the effluent are not shown and were 1.8, 100.0, and 13.7% of the total Cd, Co, and Cu, respectively.

Free ionic forms of Ca, K, Mg, and Na were the predominant species of these elements in all samples (Table 10). The elevated level of PO_4 in the effluent had a marked effect on the speciation of trace elements in effluent samples (Table 10). Cadmium, cobalt, mercury, nickel, and lead were detectable in only the effluent and the predominant complexes were with PO_4, NH_3, OH, PO_4, and CO_3, respectively. The predominant form of Al in the effluent was a complex with fulvate, whereas in the wells it was predominantly as a complex with OH. Both Cr and Fe were totally complexed with CO_3 in all samples. Copper was predominantly complexed with fulvate and PO_4 in the effluent, and fulvate in the well samples. Manganese was present predominantly as a complex with PO_4 in the effluent, as a free ion in the sentinel butte aquifier wells, and as a complex with fulvate in the alluvium aquifier. The free ionic form of Mn was greater than 10% of the total Mn in all samples. Zinc was predominantly in the form of a complex with PO_4 and CO_3 in the effluent and well samples, respectively. Approximately 20% or more of the Zn in the well samples was present as free ions.

The effluent was oversaturtaed with respect to solid calcium phosphate, cadmium phosphate, magnesium phosphate, lead phosphate, zinc phosphate, aluminum hydroxide and ferric hydroxide. Samples from the sentinel butte aquifers were oversaturated with respect to solid calcium carbonate, calcium phosphate, and aluminum hydroxide. The alluvium aquifer was oversaturated with respect to calcium carbonate and phosphate, and ferric hydroxide.

Tooele, Utah site (4)

This was a slow rate infiltration site that received an average of 61 cm of wastewater per year (Table 1). Groundwater at this site was not encountered within the top 33 m of soil (4). Since the calculated evapotranspiration rate exceeded both precipitation and wastewater application, changes in groundwater quality could not be determined. This is the reason for the absence of groundwater data for this site.

The composition of the wastewater was very similar to the composition of the test area influent (Table 5). This would be expected since the test area infuent came from a holding reservoir for the initial wastewater. The concentrations of the trace elements and NO_3 are slightly higher in the test area influent as compared to the wastewater. Sodium is also much higher in the test area influent. The differences between the wastewater and test area influent are probably due to water evaporation from the holding reservoir. In general, most of the components of the control area sample were present at lower

concentrations than they were in the other samples. This is especially true for most of the trace elements, NH_3, NO_3, PO_4, and organic C. The quality of all samples was considered acceptable for normal irrigation water (4).

This data set had 13 metals and 16 ligands. GEOCHEM considered 394 possible complexes and 39 possible solids when the concentration of the respective species were calculated. Those species that were present at concentrations greater than 0.1% of the total metal are listed in Table 11. Data not shown in Table 11 were that 4.9 and 3.2% of the Cu in the wastewater and test area influent, respectively was complexed with NH_3, and 1.0% of the Hg in the test influent was complexed with NH_3.

In all three samples, the predominant form of Ca, Cd, K, Mg, and Na was the free ion (Table 11). The predominant form of Al, Cu, Fe, and Mn was as a complex with the model fulvate ligand. This was true for all three samples even though the organic C concentrations in the wastewater samples was 5-6 times that in the control area sample. Chromium was complexed totally by CO_3 and Pb was also predominantly complexed with CO_3. Mercury was complexed mainly with OH. When solids were allowed to precipitate, GEOCHEM predicted that all three samples were oversaturated with respect to solid calcium phosphate and that the wastewater was oversaturated with respect to solid calcium carbonate.

Comparison of the three samples reveals that the overall distribution of the respective species are very similar (Table 11). If Fe and Pb were excluded, the distribution of species in the wastewater

and influent samples would be almost identical. The differences between these samples can be related to differences in the concentration of Cl, CO_3, and PO_4 (Table 5 and Table 11). This is especially true for the distribution of Cd in the control influent. The concentration of both Cl and PO_4 is much lower in the control area influent sample (CO_3 is also slightly lower) than in the wastewater sample. Higher concentrations of these ligands results in more complexation of Cd in the wastewater (27.5%) than in the control area influent (6.3%).

Cape Cod, Massachusetts site (5)

The Cape Cod site was a spray irrigation system that received between 13 and 39.52 m of wastewater per year (Table 6). Practically all the components of the wastewater were present at higher concentrations than in any of the well or lysimeter samples, especially for K, NH_3, NO_3 and PO_4. The soil at this site was fairly effective in removing most of the added metals and ligands from solution. There is some movement of Ca, Mg, Na, $B(OH)_4$, Cl, NH_3, NO_3, PO_4, and SO_4 in the soil as seen by comparing the lysimeter samples with the control. The pH of the wastewater was 6.9 and the control well indicated that the site was noncalcareous.

There were 13 metals and 7 ligands in this data set. A total of 244 possible complexes and 43 possible solids were considered by GEOCHEM when the concentration of the species were calculated. Output from the program is summarized in Table 12. Only those species that were greater

than 0.1% of the total metal are listed. Unfortunately, organic C data were not available so the interaction with fulvate ligands could not be assessed.

Calcium, magnesium, potassium, manganese, and sodium were present predominantly as free ions in all three sample types (Table 12). Cadmium was predominantly a free ion while iron was predominantly present in a complex with OH. Chromium, lead, zinc, and mercury were detectable only in the wastewater. Chromium and lead were complexed predominantly with PO_4. Zinc was present as a PO_4 complex and as a free ion while mercury was almost totally complexed with OH.

The speciation of Cu was influenced by the type and concentration of ligands. In the wastewater the concentrations of $B(OH)_4$, PO_4 and NH_3 are elevated, resulting in significant copper complexation by these ligands (Table 12). The concentrations of these ligands in the 15 cm test area lysimeter sample are lower than they are in the wastewater, with copper present mainly as a free ion and as a complex with $B(OH)_4$. Concentrations of ligands are further reduced in the control sample and Cu is present as a free ion. When the program allowed solids to precipitate it was determined that the wastewater was oversaturated with solid calcium phosphate and the wastewater, control well, and 15 cm test lysimeter samples were oversaturated with solid ferric hydroxide.

It is unfortunate that no values for organic C were available for this site. The distribution of trace elements in samples from this data set should not be compared with the distribution of trace elements in the other data sets.

Boone County, Kentucky site (6)

This data set was different from the other sites selected for evaluation since leachates from sanitary landfill test cells were studied (Table 1). The chemical composition of the leachate samples taken in 1976 from the three cells is very similar (Table 7). Leachates from test cells 2A and 2B have noticeably higher concentrations of Na, PO_4, and SO_4 while test cell 2D (1976) has a higher concentration of Cd. It should be kept in mind that cells 2A and 2B were small-scale test cells whereas cell 2D was a large-scale test cell.

Leachate samples from cell 2D for 1974, 1975, and 1976 shows a decrease of most components with time (Table 9). This would be expected since the more soluble components of the refuse should be readily removed with the first increments of percolating water. A reversal of this relationship was seen with Pb.

This data set (Table 7) has 11 metals and 16 ligands. GEOCHEM considered a possible 368 complexes and 39 possible solids. Output from GEOCHEM is summarized in Table 13. Species that were present at concentrations greater than 0.1% of the total metal are listed, except for copper in test cells 2A, 2B, and 2D for 1974. In these samples, 1.0, 1.5, and 3.5% of the Cu was complexed with NH_3, respectively.

The predominant form of Na, Ca, Mg, and K was the free ion in all of the leachate samples (Table 13). Fulvate was an important ligand for

the remaining metals, especially for Cu. Iron and lead were present mainly as a complex with CO_3 and fulvate. Manganese was predominantly a free ion and a complex with fulvate. Zinc was distributed between the free ion, CO_3, and fulvate. Cadmium was present mainly as a free ion and a complex with fulvate. When solids were allowed to precipitate it was determined that the cell 2A leachate was oversaturated with solid ferric phosphate and ferric hydroxide. Cell 2B was oversaturated with solid ferric hydroxide. Cell 2D was oversaturated with solid calcium phosphate and calcium hydroxide in 1974, ferric phosphate and ferric hydroxide in 1975, and calcium phosphate and calcium hydroxide in 1976.

It has already been stated that the chemical composition of the three cells was very similar in 1976 (Table 7). These samples are also almost identical in the distribution of the metal species (Table 13). The main difference between these samples is in the distribution of Mn. Statistical analysis of the data by the authors indicated that insignificant differences existed between the cells. Our data (Table 13) suggest that the metal and ligand species present in leachates from small-scale test cells (2A and 2B) are also comparable to those from the large-scale test cell (2D).

Comparison of the three samples from cell 2D shows that the free ionic form of Na, Ca, Mg, K, Pb, Zn and Cd increased with time (Table 13). Iron was increasingly complexed by CO_3 with time. These shifts in specification are probably a result of decreasing metal and ligand concentrations with time (Table 7).

DISCUSSION

Typical experimental studies conducted involve only total metal and ligand analyses. A further interpretation of this data involves the use of an equilibrium chemical model (GEOCHEM) to calculate the various metal-ligand species that can be present in the solution. It should be noted that it is possible to measure directly the activity or concentration of selected chemical species in natural systems (e.g., specific ion electrode for cadmium). Several general conclusions regarding the fate of macro and micro elements in soil systems treated with waste materials are apparent from data analyses conducted.

The free ion is the predominant species present for many of the major constituents of wastewaters, soil solutions, and groundwaters. This is especially true for alkali metals such as Na and K. In all systems stuied, in excess of 99% of the total concentration of Na and K was present as the free ion. Essentially no complexes were formed between Na and K and either inorganic or organic ligands present in the solutions. In contrast, calcium and magnesium were primarily present as a free metal ion but significant percentages could be present as inorganic complexes with sulfate, carbonate or phosphate. Less than 5% of these alkaline earth metals were complexed with soluble soil organic carbon. These data are relevant from the standpoint of evaluating cation exchange processes that can occur following land application of

wastewaters. Monovalent cationic species will be involved in cation exchange reactions with inorganic and organic soil colloids. The importance of complexation in altering retention of cations by exchange reactions is apparent by considering that all sulfate complexes of calcium and magnesium will have no charge and therefore these species can readily move through the soil profile as neutral species. Similarly, some of the phosphate complexes present could also have a net charge of 0. In essence, the presence of these inorganic species can result in the maintenance of soluble calcium and magnesium in solution even though one would predict that exchange reactions would occur.

The results of this study also indicate the importance of soluble organic carbon in controlling the speciation of trace metals. The majority of the samples evaluated contained from 10 to 50 mg C/ℓ while some effluents contained in excess of 200 mg C/ℓ. Even with natural solutions contained soluble organic carbon at concentrations of 10 to 20 mg C/ℓ, it was possible to get appreciable percentages of total trace metals being present as soluble organic complexes. Additional data is required to evaluate critically the importance of soluble organic metal complexes in natural systems. The approach utilized in this study was to adopt the model proposed by Mattigod and Sposito (1979) wherein a mixture of organic acids was used to simulate the acid-base and metal complexation properties of soluble organic carbon. The GEOCHEM calculations conducted indicate that speciation of copper and manganese is significantly influenced by the amount of soluble organic carbon

present. In many systems, in excess of 70 to 80% of the total Cu and Mn were present as soluble complexes. Depending on the relative concentrations of metal and organic carbon, it was also found that significant concentrations of iron, aluminum, nickel, cadmium and zinc could be present as complexes. The calculations conducted also indicate the importance of the ratio of organic carbon to metal in conjunction with the stability constant for the metal organic complexes.

An additional output of the research conducted was the significant contribution of borate complexes to the total concentration of trace metals. Borate complexes could constitute from 10 to 20% of the total copper, zinc, lead, nickel, and manganese in many wastewater systems. In calcareous soils where borate could be present in the irrigation water, it is very possible that borate complexes for many of the above trace elements could be important in controlling the retention of metals by soils and also the subsequent plant availability of metals. Phosphate complexes were also significant species for some of the trace metals.

In conclusion, the evaluation of metal-ligand species with the computer program GEOCHEM is a useful way to assess the chemical reactions that occur following addition of wastewaters to soil systems.

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Table 1. A general description of each of the six sites selected.

Site	Climate	Type of system	Principle soil types	Years of operation	Wastewater application rate	Waste source
					- m/year --	
Hollister, California	Warm dry summers, and cool rainy winters Annual precip. = 33.4 cm	Rapid infiltration	Metz sandy loam (Alluvial)	> 30	64.6	City Slaughter house Paper recycler
Milton, Wisconsin	Continental Annual precip. = 84 cm	Rapid infiltration	Floor of an old gravel pit (Glacial till)	> 20	244	City
Dickinson, North Dakota	Semiarid, continental Annual precip. = 39.4 cm	Slow rate infiltration	Deep, sandy alluvial deposits	17	~ 1.4	City
Tooele, Utah	--	Slow rate infiltration	Silt and silty clay that overlays gravely silt	20	0.6084	City
Cape Cod	Annual precip. = 113 cm	Year round spray irrigation	Surface loam underlain by wind blown sandy loam which is underlain by medium sand (Glacial outwash)	5	13-39.52	Otis Air Force Base
Boone County, Kentucky	Annual precip. = 92.7 cm	Sanitary land-fill test cells	Nicholson silt loam	4	--	Residential, solid waste[†]

[†]This was a landfill test site and no wastewater was applied.

Table 2. Analytical data for effluent, control well and test site well samples from the Hollister, California rapid infiltration site.

Component	Units	Sample				
		Effluent	Control Well	Shallow Test Well	Intermediate Test Well	Deep Test Well
Ca	$\times 10^{-4}$ M	1.35	3.72	2.51	2.57	2.34
Cu	$\times 10^{-8}$ M	5.37	1.58	6.46	9.55	1.00
Fe	$\times 10^{-7}$ M	6.92	1.45	3.80	1.55	3.80
K	$\times 10^{-5}$ M	3.31	1.32	3.31	2.40	1.41
Mg	$\times 10^{-4}$ M	2.63	3.89	2.95	3.72	3.16
Mn	$\times 10^{-7}$ M	1.29	ND †	23.4	9.77	1.82
Na	$\times 10^{-2}$ M	1.15	1.15	1.07	1.12	0.59
Ni	$\times 10^{-8}$ M	8.71	ND	17.0	17.0	6.61
Pb	$\times 10^{-8}$ M	2.63	ND	4.79	3.89	3.24
Zn	$\times 10^{-8}$ M	7.41	1.38	11.2	28.8	15.1
$B(OH)_4$	$\times 10^{-5}$ M	1.29	1.02	1.12	1.29	0.55
Cl	$\times 10^{-4}$ M	7.94	7.94	7.94	8.32	2.29
CO_3	$\times 10^{-4}$ M	7.24	9.33	8.91	9.77	7.08
F	$\times 10^{-6}$ M	3.72	2.09	5.75	1.58	1.58
NH_3	$\times 10^{-8}$ M	7.41	ND	ND	ND	ND
NO_3	$\times 10^{-6}$ M	3.09	27.5	8.51	50.1	3.31
PO_4	$\times 10^{-6}$ M	33.9	0.195	21.9	0.224	0.098
SO_4	$\times 10^{-4}$ M	2.24	2.04	1.70	1.91	1.51
Organic C	mg/ℓ	248	ND	9.98	ND	19.92
pH		7.3	7.6	7.5	7.6	7.9

† ND, nondetectable

Table 3. Composition of effluent, infiltration lagoon, control well and test site well samples from the Milton, Wisconsin rapid infiltration site.

Component	Units	Sample				
		Effluent	Infiltration Lagoon	Deep Control Well	Shallow Test Well	Deep Test Well
Ca	$\times 10^{-3}$ M	1.75	1.60	2.01	1.72	1.90
Fe	$\times 10^{-5}$ M	ND †	ND	ND	3.40	3.76
Mg	$\times 10^{-3}$ M	1.52	1.48	1.52	1.56	1.77
Mn	$\times 10^{-6}$ M	ND	ND	ND	6.55	2.00
K	$\times 10^{-4}$ M	3.58	3.68	5.37	3.45	3.43
Na	$\times 10^{-3}$ M	6.39	6.52	3.91	6.05	5.44
Zn	$\times 10^{-5}$ M	0.34	ND	2.73	0.93	1.52
AsO_4	$\times 10^{-7}$ M	1.47	0.93	0.66	2.00	10.1
$B(OH)_4$	$\times 10^{-5}$ M	6.30	5.78	2.29	6.13	5.09
Cl	$\times 10^{-3}$ M	5.64	5.30	0.65	5.16	4.71
CO_3	$\times 10^{-3}$ M	4.10	4.07	2.82	4.29	4.22
NH_3	$\times 10^{-3}$ M	1.36	1.37	0.0143	1.40	1.57
NO_3	$\times 10^{-4}$ M	3.79	2.64	4.79	0.64	0.57
PO_4	$\times 10^{-5}$ M	7.37	4.42	0.053	7.90	1.77
SeO_4	$\times 10^{-8}$ M	15.2	6.33	6.33	6.33	6.33
SO_4	$\times 10^{-4}$ M	5.31	6.14	4.48	3.54	2.81
Organic C	mg/ℓ	36	49	11	21	11
pH		7.7	8.1	7.6	7.5	7.6

†ND, nondetectable

Table 4. Analytical data for the effluent, control well, and aquifer samples from the Dickinson, North Dakota slow rate irrigation site.

Component	Units	Sample			
		Effluent	Control Sentinel Butte Aquifer	Test Sentinel Butte Aquifer	Test Alluvium Aquifer
Al	$\times 10^{-5}$ M	1.85	9.63	3.33	ND †
Ca	$\times 10^{-3}$ M	1.37	1.05	11.9	4.64
Cd	$\times 10^{-8}$ M	8.90	ND	ND	ND
Co	$\times 10^{-7}$ M	3.39	ND	ND	ND
Cr	$\times 10^{-7}$ M	3.85	ND	4.81	5.19
Cu	$\times 10^{-7}$ M	3.15	ND	8.18	3.62
Fe	$\times 10^{-5}$ M	1.25	5.01	2.69	3.58
Hg	$\times 10^{-9}$ M	4.99	ND	ND	ND
K	$\times 10^{-4}$ M	6.14	1.33	2.53	3.20
Mg	$\times 10^{-4}$ M	6.17	4.93	15.6	23.9
Mn	$\times 10^{-6}$ M	0.91	1.82	15.6	20.0
Na	$\times 10^{-2}$ M	1.33	2.10	3.19	2.24
Ni	$\times 10^{-7}$ M	8.52	ND	ND	ND
Pb	$\times 10^{-7}$ M	4.83	ND	ND	ND
Zn	$\times 10^{-6}$ M	0.77	1.04	4.50	2.10
AsO_4	$\times 10^{-8}$ M	8.91	5.49	17.8	19.2
$B(OH)_4$	$\times 10^{-5}$ M	8.52	6.11	4.49	798
Cl	$\times 10^{-3}$ M	2.34	0.51	1.52	2.91
CO_3	$\times 10^{-3}$ M	2.57	5.43	7.00	5.58
NH_3	$\times 10^{-5}$ M	49.3	2.14	49.3	2.14
NO_3	$\times 10^{-5}$ M	10.7	1.43	6.43	16.4
PO_4	$\times 10^{-6}$ M	2190	1.94	1.29	0.97
SeO_4	$\times 10^{-8}$ M	8.87	8.87	25.3	27.9
SO_4	$\times 10^{-3}$ M	3.74	5.36	17.5	27.7
Organic C	mg/ℓ	38.2	10.7	21.7	34.4
pH		8.7	8.1	7.8	7.2

†ND, nondetectable

Table 5. Chemical analysis of wastewater, test area influent, and control area influent samples taken from the Tooele, Utah slow rate irrigation site.

Component	Units	Sample		
		Wastewater	Test Area Influent	Control Area Influent
Al	$\times 10^{-9}$ M	3.52	5.56	5.70
Ca	$\times 10^{-3}$ M	5.88	5.53	4.39
Cd	$\times 10^{-12}$ M	2.67	2.67	1.78
Cr	$\times 10^{-11}$ M	11.5	42.3	9.62
Cu	$\times 10^{-11}$ M	14.2	21.7	7.56
Fe	$\times 10^{-10}$ M	4.67	10.0	4.12
Hg	$\times 10^{-11}$ M	1.89	4.14	3.24
K	$\times 10^{-5}$ M	27.1	26.9	2.56
Mg	$\times 10^{-4}$ M	2.84	4.15	4.86
Mn	$\times 10^{-10}$ M	2.73	3.83	2.19
Na	$\times 10^{-4}$ M	8.70	51.3	7.83
Pb	$\times 10^{-11}$ M	1.45	1.54	1.35
Cl	$\times 10^{-4}$ M	38.8	37.8	5.97
CO_3	$\times 10^{-3}$ M	2.56	2.56	2.01
NH_3	$\times 10^{-4}$ M	4.00	4.25	0.0033
NO_3	$\times 10^{-5}$ M	48.9	57.9	3.53
PO_4	$\times 10^{-4}$ M	2.80	2.71	0.0058
SO_4	$\times 10^{-4}$ M	6.14	6.95	2.36
Organic C	mg/ℓ	26.0	30.1	4.77
pH		7.9	7.6	7.4

Table 6. Analytical data of wastewater, control well, and test site lysimeter samples from the Cape Cod water renovation site.

Component	Units	Sample			
		Wastewater	Control well	15 cm test lysimeter	61 cm test lysimeter
Ca	$\times 10^{-4}$ M	2.69	0.39	3.93	3.57
Cd	$\times 10^{-9}$ M	2.13	ND †	ND	ND
Cr	$\times 10^{-7}$ M	1.92	ND	ND	ND
Cu	$\times 10^{-7}$ M	7.87	3.15	2.78	ND
Fe	$\times 10^{-6}$ M	9.00	0.25	1.10	ND
Hg	$\times 10^{-9}$ M	1.35	ND	ND	ND
K	$\times 10^{-5}$ M	38.9	4.78	2.09	2.52
Mg	$\times 10^{-4}$ M	1.56	0.74	1.87	1.07
Mn	$\times 10^{-7}$ M	3.82	1.91	0.77	ND
Na	$\times 10^{-3}$ M	1.65	0.29	1.56	2.73
Pb	$\times 10^{-9}$	2.61	ND	ND	ND
Zn	$\times 10^{-7}$ M	7.19	ND	ND	ND
$B(OH)_4$	$\times 10^{-6}$ M	48.4	1.85	27.8	63.8
Cl	$\times 10^{-4}$ M	7.55	3.10	6.95	13.7
NH_3	$\times 10^{-7}$ M	5310	7.14	9.29	29.7
NO_3	$\times 10^{-6}$ M	727	3.64	9.00	19.9
PO_4	$\times 10^{-6}$ M	221	0.35	3.42	1.85
SO_4	$\times 10^{-4}$ M	2.33	0.73	2.01	3.64
pH		6.91	5.50	6.63	6.60

† ND, nondetectable

Table 7. Analytical data for landfill leachate samples taken from test cells 2A, 2B, and 2D at the Boone County, Kentucky site.

		Cell				
		2A	2B	2D		
Component	Units	1976	1976	1974	1975	1976
Ca	x 10^{-2} M	2.19	2.69	1.81	1.58	2.29
Cd	x 10^{-7} M	0.62	0.60	26.9	2.57	6.91
Cu	x 10^{-6} M	1.00	1.10	1.10	ND †	0.79
Fe	x 10^{-2} M	1.45	1.12	1.29	0.98	1.86
K	x 10^{-3} M	7.59	9.33	17.8	8.71	7.59
Mg	x 10^{-3} M	3.89	8.51	11.2	3.63	2.76
Mn	x 10^{-4} M	2.82	2.95	6.03	3.89	4.47
Na	x 10^{-2} M	0.98	1.15	3.24	1.38	0.012
Pb	x 10^{-7} M	0.48	7.08	3.39	3.98	7.76
Zn	x 10^{-4} M	3.02	5.50	4.47	2.14	0.83
Cl	x 10^{-3} M	4.27	7.08	28.2	24.5	6.61
CO_3	x 10^{-2} M	5.37	5.62	10.0	5.37	6.61
NH_4	x 10^{-2} M	1.95	2.82	3.98	1.66	2.04
NO_2	x 10^{-3} M	ND	ND	ND	2.34	ND
NO_3	x 10^{-4} M	ND	ND	ND	2.57	ND
PO_4	x 10^{-4} M	1.48	0.78	3.55	2.63	0.69
SO_4	x 10^{-3} M	2.69	2.69	7.24	4.90	0.55
Organic C	mg/ℓ	15.19	15.19	10.79	15.19	15.19
pH		5.0	5.1	5.4	5.2	5.5

†ND, nondetectable

Table 8. Distribution of metal species in effluent and well water samples taken at different depths from the Hollister, California site.

Source	Metal	Distribution					
		Free	CO_3	SO_4	$B(OH)_4$	OH	Fulvate
		%					
Control well	Na	99.7	0.1	0.2	0.0	0.0	--
	Ca	97.3	0.9	1.5	0.0	0.0	--
	Mg	97.9	0.7	1.2	0.0	0.0	--
	K	99.8	0.0	0.0	0.0	0.0	--
	Ca	15.9	55.9	0.0	24.7	3.3	--
	Fe	1.1	98.7	0.0	0.0	0.2	--
	Mn	--	--	--	--	--	--
	Ni	--	--	--	--	--	--
	Pb	--	--	--	--	--	--
	Zn	63.0	29.4	1.2	3.1	3.2	--
Effluent	Na	99.6	0.0	0.2	0.0	0.0	0.0
	Ca	66.7	0.4	1.2	0.0	0.0	29.3
	Mg	94.8	0.5	1.4	0.0	0.0	2.2
	K	99.8	0.0	0.1	0.0	0.0	0.0
	Cu	0.0	0.0	0.0	0.0	0.0	100.0
	Fe	0.0	0.0	0.0	0.0	0.0	100.0
	Mn	0.0	0.0	0.0	0.0	0.0	100.0
	Ni	17.7	14.6	0.3	1.4	0.0	65.2
	Pb	9.7	62.5	0.4	0.2	3.1	22.6
	Zn	41.2	12.6	1.0	1.3	0.8	41.8
Shallow well	Na	99.7	0.1	0.1	0.0	0.0	0.0
	Ca	96.9	0.8	1.4	0.0	0.0	0.1
	Mg	97.4	0.6	1.1	0.0	0.0	0.0
	K	99.8	0.0	0.0	0.0	0.0	0.0
	Cu	0.3	1.3	0.0	0.7	0.0	97.4
	Fe	0.0	3.7	0.0	0.0	0.0	96.3
	Mn	0.0	0.0	0.0	0.0	0.0	100.0
	Ni	39.3	50.4	0.6	4.3	0.1	3.7
	Pb	7.4	86.4	0.2	0.2	3.9	0.7
	Zn	64.4	27.1	1.2	2.8	2.3	0.5
Intermediate test well	Na	99.7	0.1	0.1	0.0	0.0	--
	Ca	97.3	1.0	1.5	0.0	0.0	--
	Mg	97.9	0.7	1.2	0.0	0.0	--
	K	99.8	0.0	0.0	0.0	0.0	--
	Cu	10.2	56.2	0.2	30.1	0.1	--
	Fe	0.0	99.8	0.0	0.0	0.2‡	--
	Mn	87.9	8.9	6.3	1.7	0.0	--
	Ni	36.4	57.2	0.6	5.7	0.2	--
	Pb	5.8	89.7	0.2	0.3	3.9	--
	Zn	62.1	29.8	1.2	3.9	3.0	--

Table 8. Continued

Source	Metal	Distribution					
		Free	CO_3	SO_4	$B(OH)_4$	OH	Fulvate
		%					
Deep test well	Na	99.8	0.0	0.1	0.0	0.0	0.0
	Ca	95.5	0.9	1.4	0.0	0.0	2.1
	Mg	98.0	0.7	1.1	0.0	0.0	0.0
	K	99.9	0.0	0.0	0.0	0.0	0.0
	Cu	0.0	0.0	0.0	0.0	0.0	99.9
	Fe	0.0	5.9	0.0	0.0	0.0	94.1
	Mn	0.0	0.0	0.0	0.0	0.0	100.0
	Ni	27.6	52.9	0.4	3.8	0.3	14.9
	Pb	3.9	89.1	0.1	0.2	5.7	0.8
	Zn	57.7	26.3	1.1	3.1	8.0	3.7

‡ Solution was oversaturated with suspect to solid $Fe(OH)_3$.

Table 9. Distribution of metal species in effluent, holding lagoon effluent, and groundwater samples taken from the Milton, Wisconsin rapid infiltration site.

Source	Metal	Distribution					
		Free	CO_3	SO_4	Cl	PO_4	Fulvate
		%					
Effluent	Ca	90.5	3.5†	2.9	1.2	0.8‡	0.8
	Fe	--	--	--	--	--	--
	K	99.3	0.2	0.2	0.2	0.0	0
	Mg	92.6	2.6	2.4	1.0	1.3	0
	Mn	--	--	--	--	--	--
	Na	98.8	0.5	0.3	0.4	0.0	0
	Zn	29.1	54.1	1.2	0.1	1.8	1.2
Infiltration lagoon	Ca	88.8	4.7†	3.4	1.1	0.6‡	1.3
	Fe	--	--	--	--	--	--
	K	99.3	0.3	0.2	0.2	0.0	0
	Mg	92.0	3.3	2.8	0.9	0.9	0
	Mn	--	--	--	--	--	--
	Na	98.8	0.5	0.4	0.3	0.0	0
	Zn	--	--	--	--	--	--
Deep control well	Ca	94.0	2.6	2.8	0.2	0.0	0.2
	Fe	--	--	--	--	--	--
	K	99.6	0.2	0.2	0.0	0.0	0
	Mg	95.6	2.0	2.3	0.1	0.0	0
	Mn	--	--	--	--	--	--
	Na	99.3	0.3	0.3	0.0	0.0	0
	Zn	39.3	52.5¶	1.5	0.0	0.0	0.1
Shallow test well	Ca	92.6	3.4†	1.9	1.1	0.8‡	0
	Fe	0.0	99.4	0.0	0.0	0.0	0.6
	K	99.4	0.2	0.1	0.2	0.0	0
	Mg	93.7	2.5	1.6	0.9	1.3	0
	Mn	1.3	0.5	0.0	0.0	0.0	98
	Na	98.9	0.5	0.2	0.3	0.0	0
	Zn	32.1	56.5	0.8	0.0	1.6	0.1
Deep test well	Ca	93.7	3.5†	1.5	1.0	0.2‡	1.9
	Fe	0.0	98.1	0.0	0.0	0.0	0
	K	99.4	0.2	0.1	0.2	0.0	0
	Mg	95.0	2.6	1.2	0.8	0.3	0
	Mn	0.3	0.0	0.0	0.0	0.0	99.6
	Na	99.0	0.5	0.2	0.3	0.0	0
	Zn	32.0	57.5¶	0.6	0.1	0.4	0

† Oversaturated with respect to calcium carbonate.
‡ Oversaturated with respect to calcium phosphate.
¶ Oversaturated with respect to zinc carbonate.

Table 10. Distribution of metal species in effluent, control groundwater and test site groundwater samples taken from the Dickinson, North Dakota slow rate irrigation site.

Source	Metal	Distribution							
		Free	CO_3	SO_4	Cl	PO_4	$B(OH)_4$	OH	Fulvate
		%							
Effluent	Al	0.0	0.0	0.0	0.0	0.0	2.3	31.6[†]	66.1
	Ca	50.5	3.5	11.0	0.3	34.5[δ]	0.0	0.0	0.0
	Cd	28.0	16.5	9.7	3.7	35.6[‡]	2.3	0.8	1.4
	Co	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cr	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cu	0.0	1.9	0.0	0.0	33.3	7.7	0.0	43.3
	Fe	0.0	100.0	0.0	0.0	0.0	0.0	0.0[¶]	0.0
	Hg	0.0	0.0	0.0	0.0	0.0	0.0	99.3	0.0
	K	97.2	0.2	1.4	0.0	1.1	0.0	0.0	0.0
	Mg	48.5	1.9	8.4	0.2	40.8[††]	0.0	0.0	0.0
	Mn	13.8	16.3	3.0	0.0	52.3	14.3	0.1	0.0
	Na	95.9	0.3	2.3	0.1	1.4	0.0	0.0	0.0
	Ni	1.4	31.9	0.3	0.0	49.7	11.5	0.0	5.1
	Pb	0.1	60.8	0.0	0.0	33.0[#]	4.6	1.3	0.5
	Zn	4.1	12.0	1.1	0.0	58.4[‡‡]	13.3	10.4	0.5
Control sentinel butte aquifer	Al	0.0	0.0	0.0	0.0	0.0	0.3	96.1[†]	3.6
	Ca	76.5	4.7[†††]	18.6	0.0	0.0[δ]	0.0	0.0	0.0
	Cd	--	--	--	--	--	--	--	--
	Co	--	--	--	--	--	--	--	--
	Cr	--	--	--	--	--	--	--	--
	Cu	--	--	--	--	--	--	--	--
	Fe	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hg	--	--	--	--	--	--	--	--
	K	98.0	0.3	1.7	0.0	0.0	0.0	0.0	0.0
	Mg	80.9	3.3	15.7	0.0	0.0	0.0	0.0	0.0
	Mn	44.1	35.0	10.8	0.0	0.0	9.8	0.1	0.0
	Na	96.6	0.6	2.8	0.0	0.0	0.0	0.0	0.0
	Ni	--	--	--	--	--	--	--	--
	Pb	--	--	--	--	--	--	--	--
	Zn	19.7	55.5	6.1	0.0	0.0	13.9	0.0	0.0

Table 10. Continued

Source	Metal	Distribution							
		Free	CO_3	SO_4	Cl	PO_4	$B(OH)_4$	OH	Fulvate
		---------- % ----------							
Test sentinel butte aquifer	Al	0.0	0.0 †††	0.0	0.0	0.0 δ	0.0	79.1 †	20.9
	Ca	66.4	3.3	0.0	0.1	0.0	0.0	0.0	0.0
	Cd	--	--	--	--	--	--	--	--
	Co	--	--	--	--	--	--	--	--
	Cr	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cu	0.7	30.4	0.4	0.0	0.0	11.4	0.3	55.6
	Fe	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hg	--	--	--	--	--	--	--	--
	K	95.8	0.3	3.8	0.0	0.0	0.0	0.0	0.0
	Mg	71.6	2.6	25.7	0.1	0.0	0.0	0.0	0.0
	Mn	47.9	26.6	21.6	0.0	0.0	3.6	0.0	0.0
	Na	92.9	0.7	6.4	0.0	0.0	0.0	0.0	0.0
	Ni	--	--	--	--	--	--	--	--
	Pb	--	--	--	--	--	--	--	--
	Zn	23.3	55.7	13.3	0.0	0.0	5.6	1.7	0.1
Test alluvium aquifer	Al	--	-- †††	--	--	-- δ	--	--	--
	Ca	60.7	1.6	37.3	0.2	0.0	0.0	0.0	0.0
	Cd	--	--	--	--	--	--	--	--
	Co	--	--	--	--	--	--	--	--
	Cr	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cu	2.3	16.3	1.8	0.0	0.0	14.5	0.2	64.3
	Fe	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hg	--	--	--	--	--	--	--	--
	K	94.3	0.2	5.4	0.0	0.0	0.0	0.0	0.0
	Mg	66.1	1.4	32.3	0.2	0.0	0.0	0.0	0.0
	Mn	23.8	5.7	14.6	0.0	0.0	0.8	0.0	54.9
	Na	90.6	0.4	8.8	0.1	0.0	0.0	0.0	0.0
	Ni	--	--	--	--	--	--	--	--
	Pb	--	--	--	--	--	--	--	--
	Zn	30.9	41.2	23.9	0.0	0.0	3.4	0.4	0.0

† Oversaturated with respect to aluminum hydroxide.
‡ Oversaturated with respect to cadmium phosphate.
δ Oversaturated with respect to calcium phosphate.
¶ Oversaturated with respect to ferric hydroxide.
# Oversaturated with respect to lead phosphate.
†† Oversaturated with respect to magnesium phosphate.
‡‡ Oversaturated with respect to zinc phosphate.
††† Oversaturated with respect to calcium carbonate.

Table 11. Distribution of metal species in initial effluent, test area influent, and control area influent that was applied to the Tooele, Utah slow rate irrigation site.

Source	Metal	Distribution						
		Free	CO_3	SO_4	Cl	PO_4	OH	Fulvate
		%						
Wastewater	Al	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	Ca	92.8	0.4†	2.9	0.8	2.7‡	0.0	0.1
	Cd	70.3	2.7	3.5	15.7	5.6	0.3	0.9
	Cr	0.0	100.0	0.0	0.0	0.0	0.0	0.0
	Cu	0.0	0.4	0.0	0.0	1.0	0.0	93.6
	Fe	0.0	12.9	0.0	0.0	0.0	0.3	86.8
	Hg	0.0	0.0	0.0	2.4	0.0	96.8	0.0
	K	99.5	0.0	0.2	0.2	0.0	0.0	0.0
	Mg	92.8	0.3	2.3	0.6	4.0	0.0	0.0
	Mn	0.2	0.0	0.0	0.0	0.0	0.0	99.7
	Na	99.3	0.0	0.3	0.2	0.1	0.0	0.0
	Pb	7.0	66.4	0.4	0.7	16.0	8.5	1.1
Influent test area	Al	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	Ca	93.2	0.2	3.1	0.8	2.3‡	0.0	0.2
	Cd	72.5	1.2	3.8	15.5	5.2	0.2	1.1
	Cr	0.0	100.0	0.0	0.0	0.0	0.0	0.0
	Cu	0.1	0.1	0.0	0.0	0.8	0.0	95.6
	Fe	0.0	0.0	0.0	0.0	0.0	0.0	99.9
	Hg	0.0	0.0	0.0	8.1	0.0	90.9	0.0
	K	99.5	0.0	0.2	0.1	0.0	0.0	0.0
	Mg	93.2	0.1	2.5	0.6	3.5	0.0	0.0
	Mn	0.0	0.0	0.0	0.0	0.0	0.0	99.9
	Na	0.0	0.0	0.4	0.2	0.1	0.0	0.0
	Pb	18.0	45.5	1.2	1.6	20.1	10.7	2.9
Influent control area	Al	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	Ca	98.3	0.1	1.3	0.1	0.0‡	0.0	0.0
	Cd	93.3	0.9	2.0	3.4	0.0	0.1	0.2
	Cr	0.0	100.0	0.0	0.0	0.0	0.0	0.0
	Cu	1.4	0.6	0.0	0.0	0.0	0.0	88.3
	Fe	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	Hg	0.0	0.0	0.0	0.6	0.0	99.4	0.0
	K	99.9	0.0	0.0	0.0	0.0	0.0	0.0
	Mg	98.7	0.0	1.1	0.1	0.0	0.0	0.0
	Mn	0.1	0.0	0.0	0.0	0.0	0.0	99.9
	Na	99.8	0.0	0.1	0.0	0.0	0.0	0.0
	Pb	37.6	44.6	1.0	0.6	0.0	15.1	1.0

† Oversaturated with respect to calcium carbonate.
‡ Oversaturated with respect to calcium phosphate.

Table 12. distribution of metal species in effluent, control well, and test area lysimeter samples from the Cape Cod site.

Sample	Metal	Distribution						
		Free	$B(OH)_4$	Cl	PO_4	SO_4	OH	NH_3
		%						
Wastewater	Ca	90.4	0.0	0.2	6.7[†]	2.4	0.0	0.0
	Cd	74.7	0.9	4.3	15.3	3.1	0.4	1.1
	Cr	0.0	0.0	0.0	99.5	0.0	0.5	0.0
	Cu	0.6	22.2	0.0	16.7	0.0	0.4	60.1
	Fe	0.0	0.0	0.0	0.5	0.0	99.5[‡]	0.0
	K	99.6	0.0	0.0	0.2	0.1	0.0	0.0
	Mg	88.2	0.0	0.2	9.7	1.8	0.0	0.0
	Mn	61.1	9.7	0.0	27.4	1.6	0.0	0.0
	Na	99.5	0.0	0.0	0.2	0.2	0.0	0.0
	Pb	11.1	10.1	0.3	61.5	0.6	16.2	0.0
	Zn	43.4	21.8	0.0	26.9	1.4	6.1	0.3
	Hg	0.0	0.0	0.1	0.0	0.0	98.6	1.3
Control well	Ca	98.9	0.0	0.1	0.0	1.0	0.0	0.0
	Cd	--	--	--	--	--	--	--
	Cr	--	--	--	--	--	--	--
	Cu	97.9	0.4	0.0	0.0	1.3	0.3	0.0
	Fe	0	0.0	0.0	0.0	0.0	100.0[‡]	0.0
	K	99.9	0.0	0.0	0.0	0.0	0.0	0.0
	Mg	99.1	0.0	0.0	0.0	0.8	0.0	0.0
	Mn	99.0	0.0	0.0	0.0	1.0	0.0	0.0
	Na	99.9	0.0	0.0	0.0	0.0	0.0	0.0
	Pb	--	--	--	--	--	--	--
	Zn	--	--	--	--	--	--	--
	Hg	--	--	--	--	--	--	--
15 cm test area lysimeter	Ca	97.6	0.0	0.2	0.0	2.2	0.0	0.0
	Cd	--	--	--	--	--	--	--
	Cr	--	--	--	--	--	--	--
	Cu	52.7	43.2	0.0	0.4	1.5	2.0	0.1
	Fe	0.0	0.0	0.0	0.0	0.0	99.9[‡]	0.0
	K	99.9	0.0	0.0	0.0	0.1	0.0	0.0
	Mg	98.1	0.0	0.2	0.0	1.7	0.0	0.0
	Mn	97.1	0.5	0.0	0.2	2.2	0.0	0.0
	Na	99.8	0.0	0.0	0.0	0.2	0.0	0.0
	Pb	--	--	--	--	--	--	--
	Zn	--	--	--	--	--	--	--
	Hg	--	--	--	--	--	--	--

Table 12. Continued

Sample	Metal	Distribution						
		Free	$B(OH)_4$	Cl	PO_4	SO_4	OH	NH_3
		%						
122 cm test area lysimeter	Ca	96.0	0.0	0.4	0.0	5.1	0.0	0.0
	Cd	--	--	--	--	--	--	--
	Cr	--	--	--	--	--	--	--
	Cu	--	--	--	--	--	--	--
	Fe	--	--	--	--	--	--	--
	K	99.7	0.0	0.0	0.0	0.2	0.0	0.0
	Mg	96.8	0.0	0.3	0.0	2.9	0.0	0.0
	Mn	--	--	--	--	--	--	--
	Na	99.6	0.0	0.1	0.0	0.3	0.0	0.0
	Pb	--	--	--	--	--	--	0.0
	Zn	--	--	--	--	--	--	0.0
	Hg	--	--	--	--	--	--	0.0

† Oversaturated with solid calcium phosphate.
‡ Oversaturated with solid ferric hydroxide.

Table 13. Distribution of metal species in landfield leachate samples taken from test cells 2A, 2B and 2D at the Boone County, KY site.

Cell	Sampling date	Metal	Distribution				
			Free	CO_3	SO_4	Cl	Fulvate
			%				
2A	8/3/76	Na	98.3	0.2	0.7	0.2	0.5
		Ca	84.1	0.7	3.4	0.4	11.2
		Mg	92.4	0.6	3.0	0.4	3.6
		K	99.3	0.0	0.4	0.1	0.0
		Cu	0.8	0.0	0.0	0.0	98.0
		Fe	0.0	61.3	0.0	0.0	38.5
		Mn	72.8	4.8	2.9	0.1	19.1
		Pb	5.9	19.9	0.5	0.3	73.2
		Zn	53.0	22.2	2.7	0.0	22.0
		Cd	42.2	3.5	2.7	5.4	46.0
2B	8/3/76	Na	98.2	0.3	0.6	0.4	0.5
		Ca	84.3	1.3	2.8	0.6	10.9
		Mg	92.7	1.1	2.4	0.6	3.1
		K	99.2	0.2	0.4	0.2	0.0
		Cu	0.6	0.1	0.0	0.0	97.7
		Fe	0.0	56.1	0.0	0.0	43.9
		Mn	60.9	7.4	2.0	0.1	29.5
		Pb	5.2	32.1	0.4	0.4	61.8
		Zn	45.2	34.4	1.9	0.0	18.3
		Cd	40.7	6.2	2.1	7.9	43.0
2D	7/2/74	Na	95.5	0.9	1.8	1.2	0.6
		Ca	77.8	3.4	6.9	2.5	9.2
		Mg	86.1	3.0	6.1	2.3	2.2
		K	97.6	0.4	1.1	0.8	0.0
		Cu	0.4	0.2	0.0	0.0	95.7
		Fe	0.0	76.9	0.0	0.0	23.1
		Mn	10.9	3.7	1.0	0.0	84.2
		Pb	3.4	59.0	0.6	1.1	35.8
		Zn	27.2	58.9	3.0	0.2	10.5
		Cd	29.2	12.6	4.1	25.2	28.5
2D	6/17/75	Na	96.3	0.3	1.4	1.3	0.8
		Ca	76.5	1.2	6.4	2.4	13.4
		Mg	87.0	1.1	5.8	2.2	3.6
		K	98.1	0.2	0.9	0.8	0.0
		Cu	0.4	0.0	0.0	0.0	98.6
		Fe	0.0	50.1	0.0	0.0	49.8
		Mn	52.2	6.4	4.3	0.4	36.3
		Pb	4.2	26.1	0.7	1.3	67.6
		Zn	40.8	31.7	4.3	0.3	22.8
		Cd	28.1	4.4	3.7	23.0	40.7

Table 13. Continued

Cell	Sampling date	Metal	Distribution				
			Free	CO_3	SO_4	Cl	Fulvate
			---------- % ----------				
2D	8/3/76	Na	98.3	0.3	0.1	0.3	0.9
		Ca	83.4	1.4	0.6	0.6	14.0
		Mg	94.4	1.3	0.5	0.6	3.1
		K	99.5	0.2	0.0	0.2	0.0
		Cu	0.1	0.0	0.0	0.0	99.1
		Fe	0.0	74.6	0.0	0.0	25.4
		Mn	39.7	5.4	0.3	0.0	54.4
		Pb	4.3	30.0	0.0	0.3	65.2
		Zn	41.1	35.1	0.4	0.0	23.3
		Cd	36.1	6.2	0.4	6.2	50.9

† Oversaturated with solid calcium phosphate.
‡ Oversaturated with solid ferric hydroxide.